Cellular Wireless Energy Harvesting for Powering Wearable Sensors

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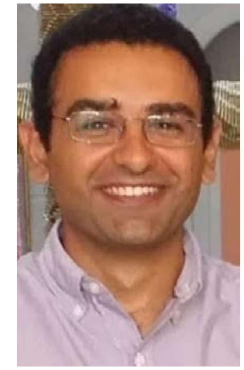
Abstract

Our generation has witnessed a surge of wearables for healthcare and fitness applications. However, real estate availability is very limited in most wearable gadgets; it is very challenging to shrink the size of the wearable device while maintaining the required space for the analog/power/RF circuits, sensors, antenna, and battery. The later typically occupies a significant space, and it has become highly desirable to completely forgo battery-based designs in favor of ones that employ a reliable mechanism of energy harvesting.
In this talk, we discuss different aspects of realizing a smart contact lens as an example of a wearable wireless sensor enabled through the utilization of electromagnetic energy harvesting. Very recently, the potential of using a smart contact lens to monitor multiple diseases through sensing various biomarkers in the tear fluid have been explored. Most notable attempts proposed utilizing near field communication (NFC) technologies to enable the operation of the smart contact lenses. This in turn necessitated that the contact lens wearer would have another device to wear close to the eye to enable the NFC operation, which is not a practical implementation to many potential users.

Alternatively, and since the habit of having a cellular phone on a person has become an intrinsic part of our daily routine, we envisioned a different energy harvesting mechanism that makes use of how ubiquitous smartphones have become. Most recently, we demonstrated the potential of harvesting ambient electromagnetic energy radiated from a nearby cell phone whether during a call or during a data session to continuously power the sensors and electronics on a contact lens for non-invasive monitoring of glucose levels in the tear fluid.
It is a fact that most smartphones emit between 20dBm to 33dBm, depending on how good their antenna designs are, their band of operation, and whether they are in a data burst or a voice call, and. Our electromagnetic energy harvesting system on the contact lens relies on rectifying a portion of a cell phone/smartphone-emitted uplink signal into DC power for the operations of on-lens sensors and components. For development purposes, an actual cow eye is used to assist in various measurements of the proposed energy harvester.
Ultimately, a minimum power of 1mW at about 1V is harvested and delivered to a resistive load of 2KOhm when a cell phone is held in a typical reading position. This harvested power level is more than adequate to enable numerous possible on-body sensors.
We will also describe in this talk how our system employs signals emitted from smartphones to facilitate the backscatter of the sensor-modulated electromagnetic waves allowing Bluetooth-enabled smartphones to display in real-time the sensor data collected on-board of the smart contact lens.

Index Terms: Smart Contact Lenses, wearable electronics, Bio-sensors, bio-telemetry, personalized assistive smartphones

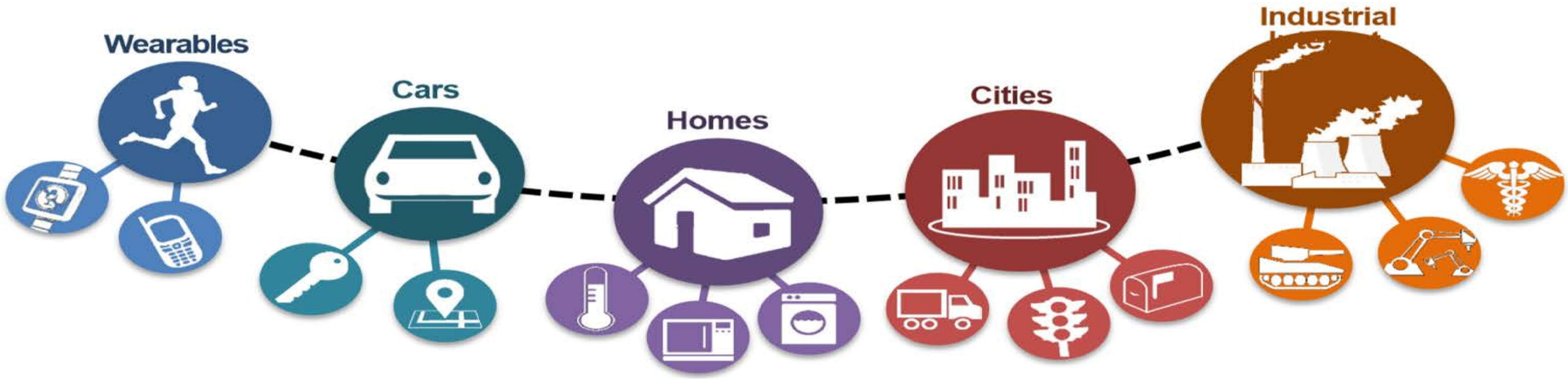
Bio



George Shaker (BASc, MASc, PhD, SM IEEE) joined Spark Tech Labs (formerly DBJay Limited) at its founding, where he is currently the Principal Scientist and Head of Electromagnetics R&D. Since fall 2014, Dr. Shaker has been an adjunct assistant professor with the department of electrical and computer Engineering at University of Waterloo. He is also affiliated with the department of mechatronics and mechanical engineering, and oversees wireless activities in the sensors and devices lab at the recently established UW-Research Institute for Aging. From 2006 to 2011, George was affiliated with RIM's (Blackberry's) RF R&D division, first as an NSERC scholar, then as a senior EM researcher, reporting directly to the RIM's vice president of RF R&D. From September 2009 to April 2010, he was a visiting NSERC MSFSS scholar at Georgia Institute of Technology. Over the last decade, George has contributed to products available from Hi-Tek International, Panasonic, ActsPower, COM DEV Limited, Research in Motion (BlackBerry), American Microelectronic Semiconductors (ON-Semiconductors), Bionym, Medella Health, Novela, DBJ, Konka, Enice, China Mobile, Tri-L Solutions, Pebble, Thalmic Labs, Lyngsoe Systems, NERv, and Spark Tech Labs.

Dr. Shaker has co-authored more than 70 journal publications, conference papers, and technical reports, along with more than 15 patents/patent applications. George has served as session co-chairman and short course/workshop lecturer in several international scientific conferences. He has served as a TPC/TPRC member of the IEEE MTT-IMS, the IEEE iWAT, the IEEE EMC, the IEEE WF-IoT, the IEEE AP-S, the IEEE EuCAP, and the IEEE iThings. He was an invited speaker at several international events, including Keynote talks at the IEEE LAPC, the IEEE iThings, and the 2015 Ambient Intelligence.

George was the recipient of multiple awards, including the NSERC Canada Graduate Scholarship (sole winner in the area of Electromagnetics across Canada, 2007, first to UWaterloo in EM), Ontario Graduate Scholarship (twice), European School of Antennas Grant at IMST-GmbH (2007), IEEE AP-S Best Paper Award (2009, top 3, first to UWaterloo), the IEEE AP-S Best Paper Award (HM, Twice, 2008, 2011), the IEEE Antennas and Propagation Graduate Research Award (2008/2009, first to UWaterloo), NSERC CGS-FSS (2009, sole winner from UWaterloo Engineering), IEEE MTT-S Graduate Fellowship (2009, first to UWaterloo), and the Electronic Components and Technology Best of Session Paper Award (2010), Google Soli Alpha (2015), IEEE AP-S Third best student design award (2016). A paper he co-authored in IEEE Sensors was among the top 25 downloaded papers on IEEEXplore for several consecutive months (2012).



Compare to the 12 Billion of Cell Phone Market!

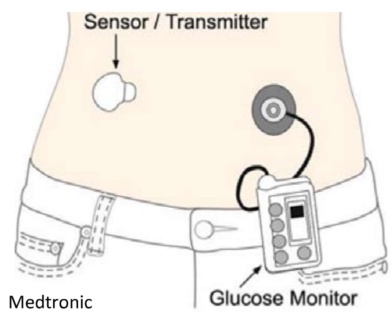
Market Sector Size /$ Billions	2015	2016	2020	2025
Health, Medical, Fitness, Wellness -Regulated	8.92	9.61	14.67	28.49
Health, Medical, Fitness, Wellness - UnRegulated	1.61	1.78	1.43	1.01
Infotainment	11.61	14.24	19.00	20.89
Industrial, Commercial, Military	1.37	1.71	4.22	7.58
Fashion & Other	0.70	0.79	2.57	6.31
TOTAL in Billions	24.21	28.13	41.89	64.28

- The strongest sectors will be health and fitness devices (largest growth) and infotainment (largest size).
- Infotainment is likely to suffer from heavy commoditization, similarly to the large, stagnant basic infotainment sectors (including simple accessories like headphones, and basic wristwatches).

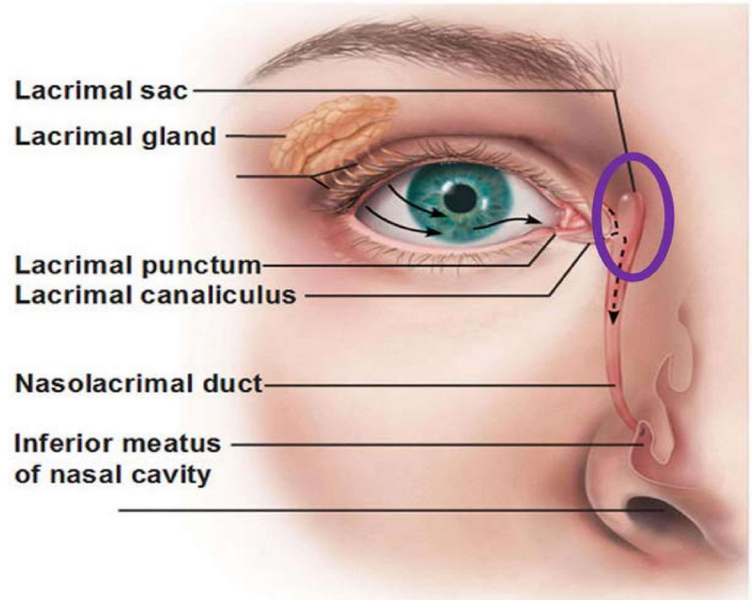
•Source: IDTechEx report **"Wearable Technology 2015-2025"** www.IDTechEx.com

Smart Contact Lenses

350 Million diabetes patients worldwide
6.5 million new patients, annually



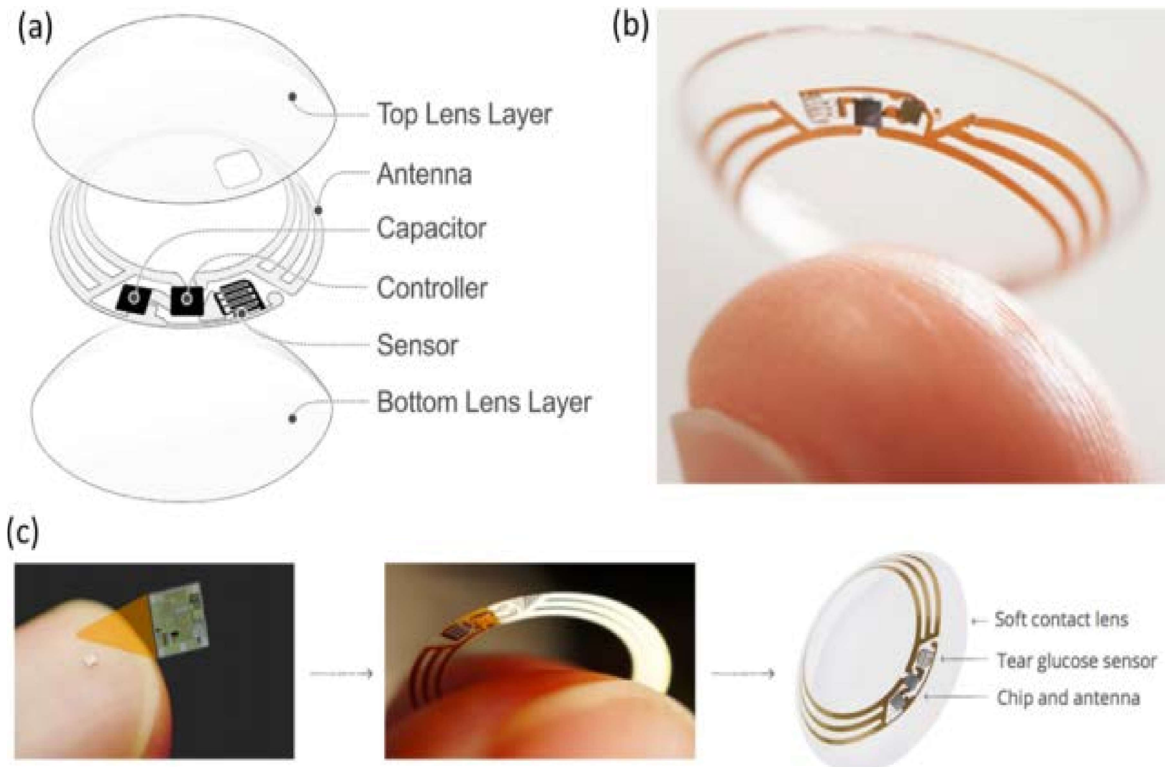
Seeking Continuous prick-free Monitoring



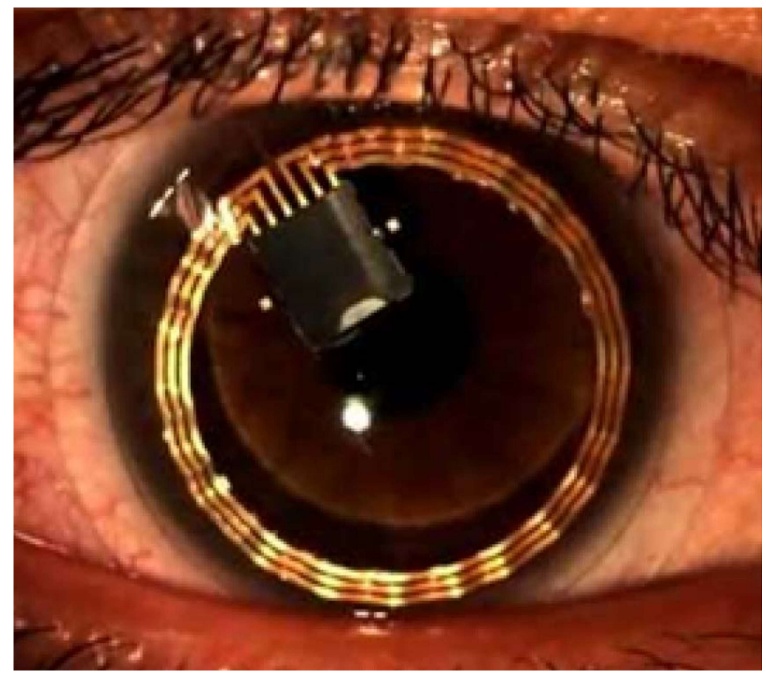
Notable biomarkers:

- Cholesterol
  - Cardiovascular condition
- Lactic Acid
  - Stamina and fitness
- Alpha 1-antichymotrypsin
  - Pathogenesis of Alzheimer
- Glucose
  - Blood sugar level

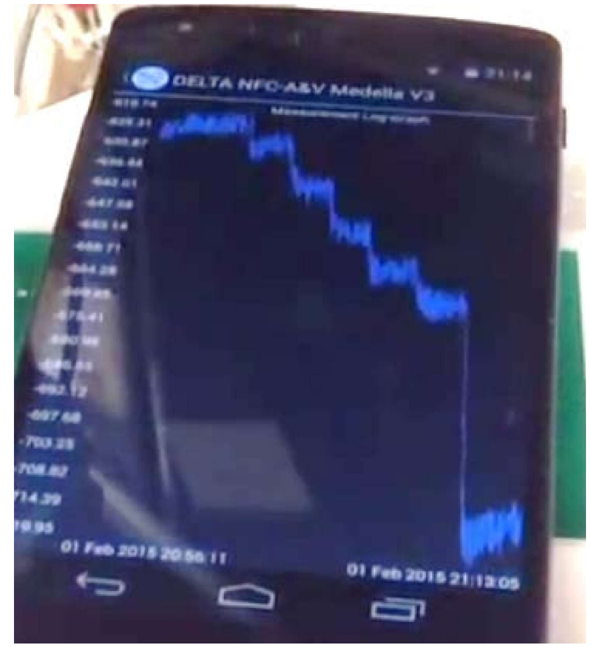
Google's smart contact lenses for diabetics: Another step towards the Google-powered cyborg

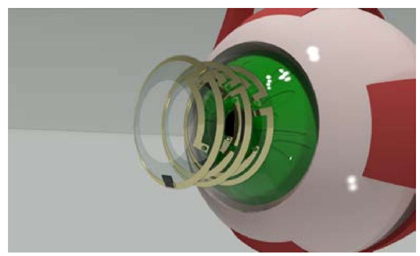


Source: Online Google Press Release



Source: Sensimed





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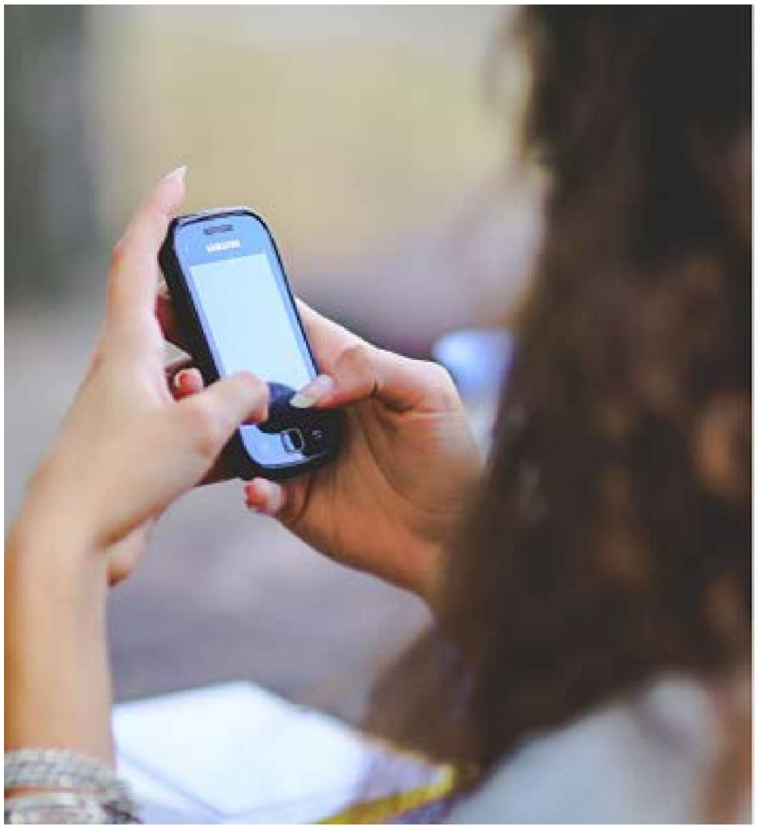
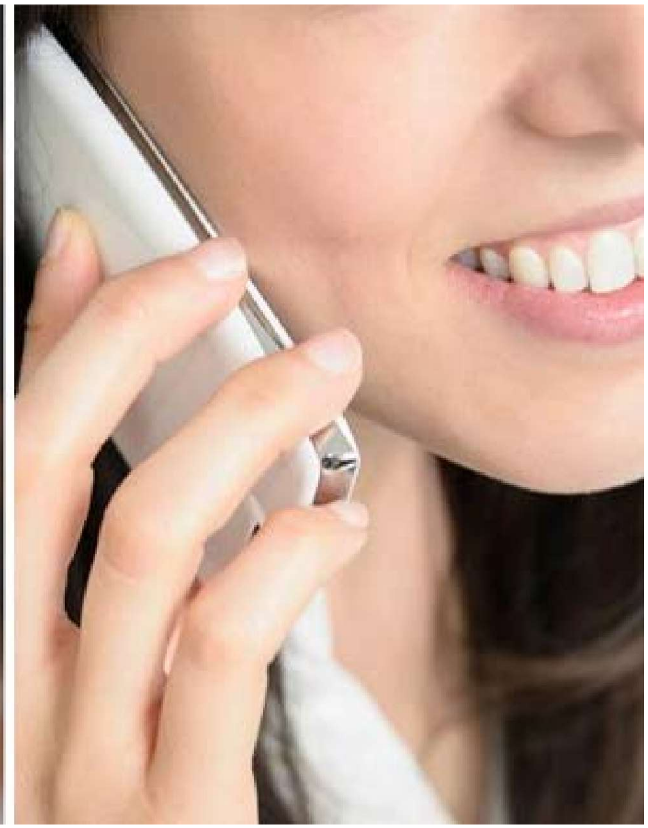
Medella Health is an International Runner-Up for the James Dyson Award

CANADIAN STARTUP NEWS & TECH INNOVATION

BY JESSICA GALANG / CANADIAN STARTUP NEWS / JUNE 2, 2016

MEDELLA HEALTH RAISES $1.4 MILLION ON ITS PATH TO CHANGE THE WAY WE MANAGE DIABETES



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June 26 - July 1, 2016
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Travel to the 2016 IEEE AP-S USNC-URSI and win up to US $1500!
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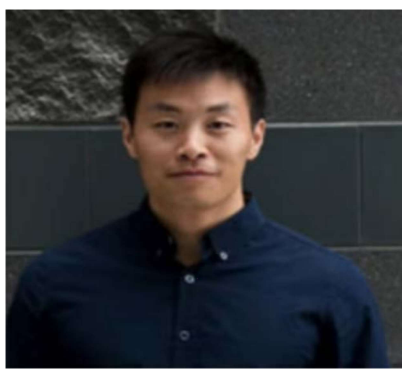
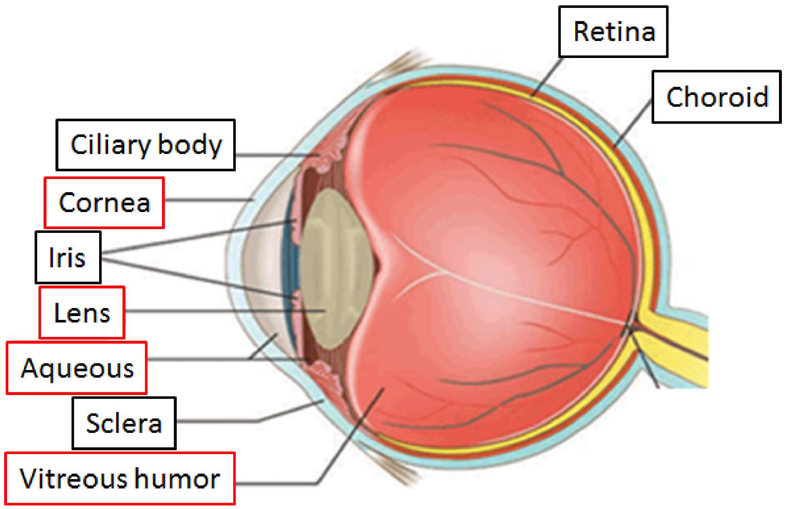
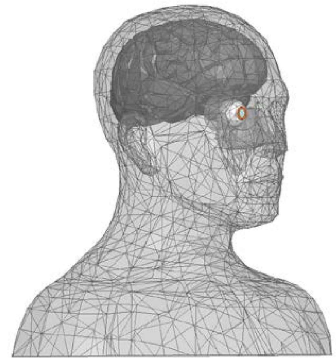
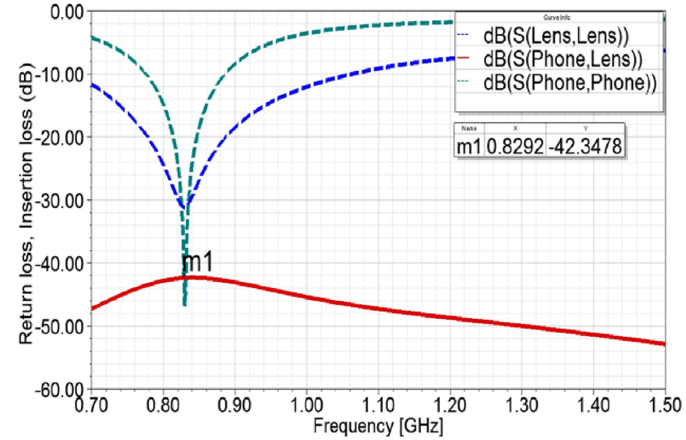
Join the 7th IEEE Antennas and Propagation Society (AP-S) Antenna Design Contest! Design and build a power-scavenging device that can harvest and convert ambient radio-frequency emissions into useful DC power. The top 3 teams will receive up to US $2,500 in travel funds to attend the IEEE Antennas and Propagation Symposium in San Juan, Puerto Rico, June 25 – July 2, 2016 to demonstrate their working systems. From these 3 teams, 1st, 2nd and 3rd place winners will be announced at the 2016 IEEE AP-S Awards Banquet at the conference and will receive cash awards

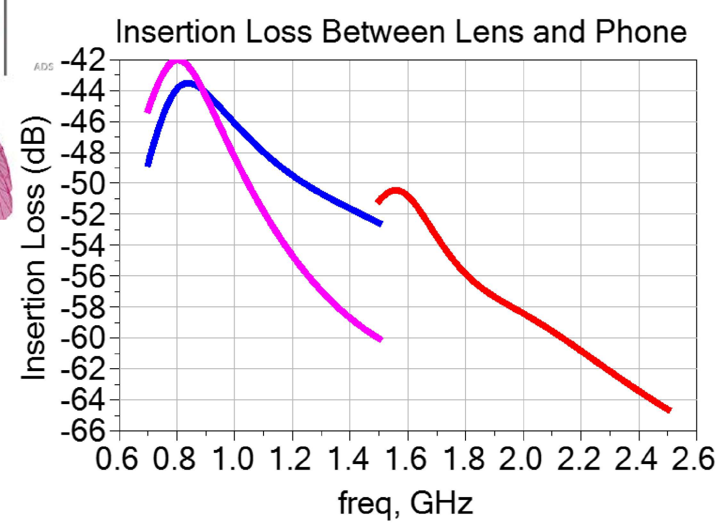


Initial Simulations

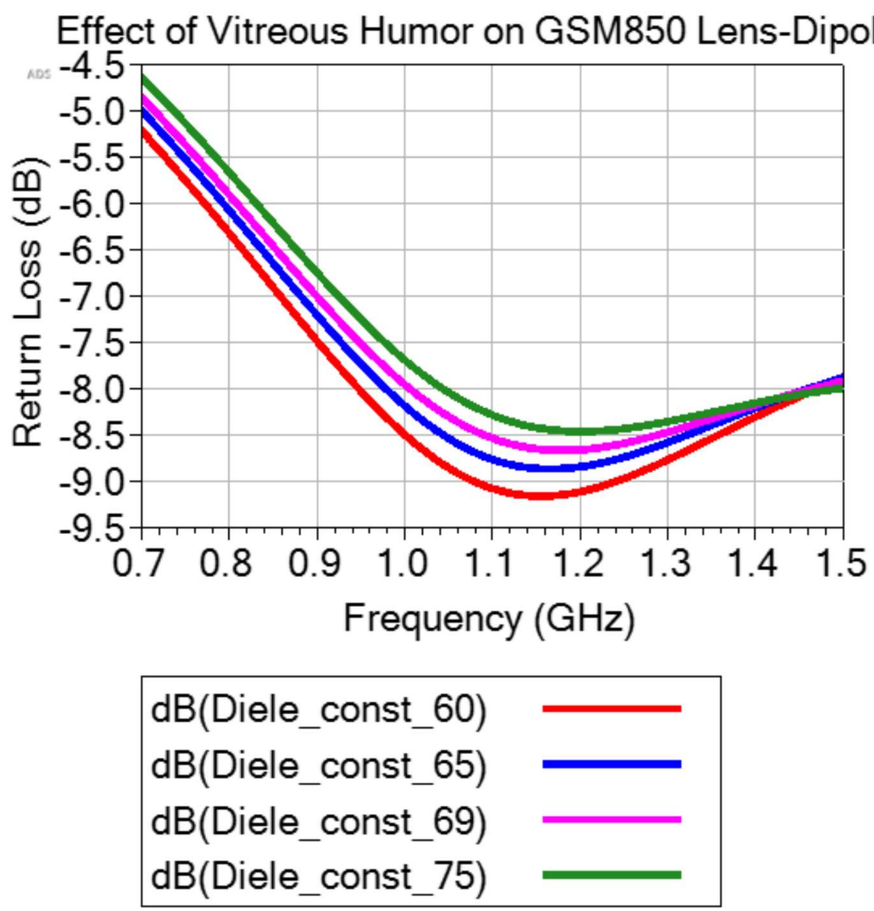


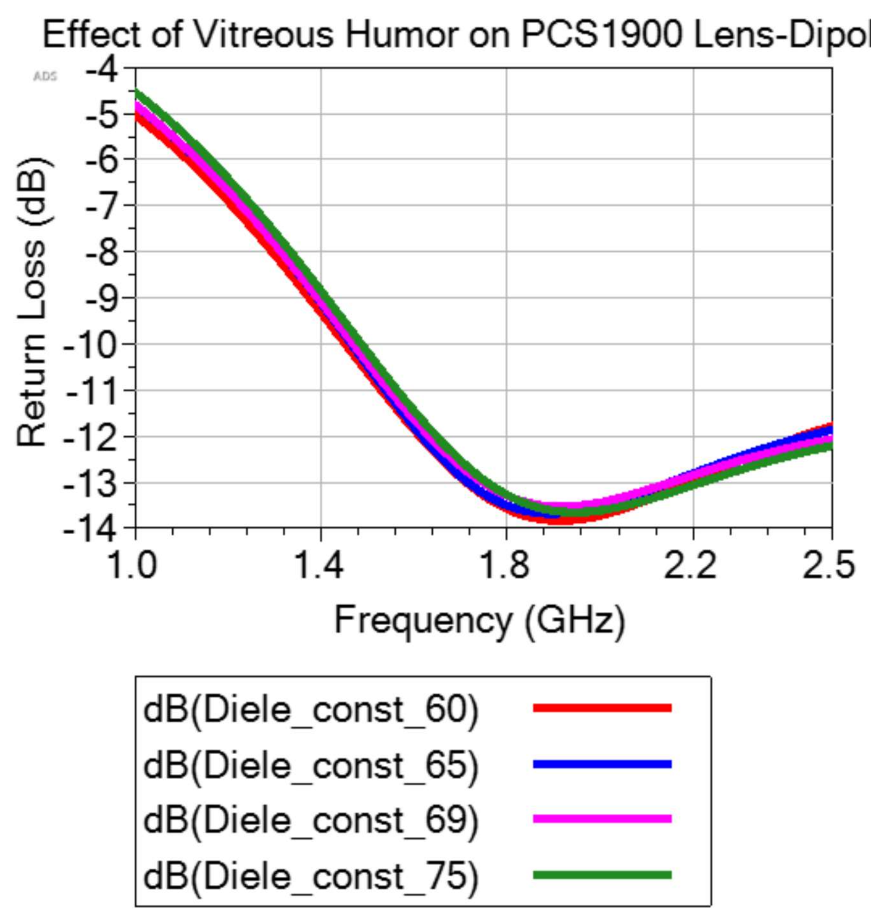




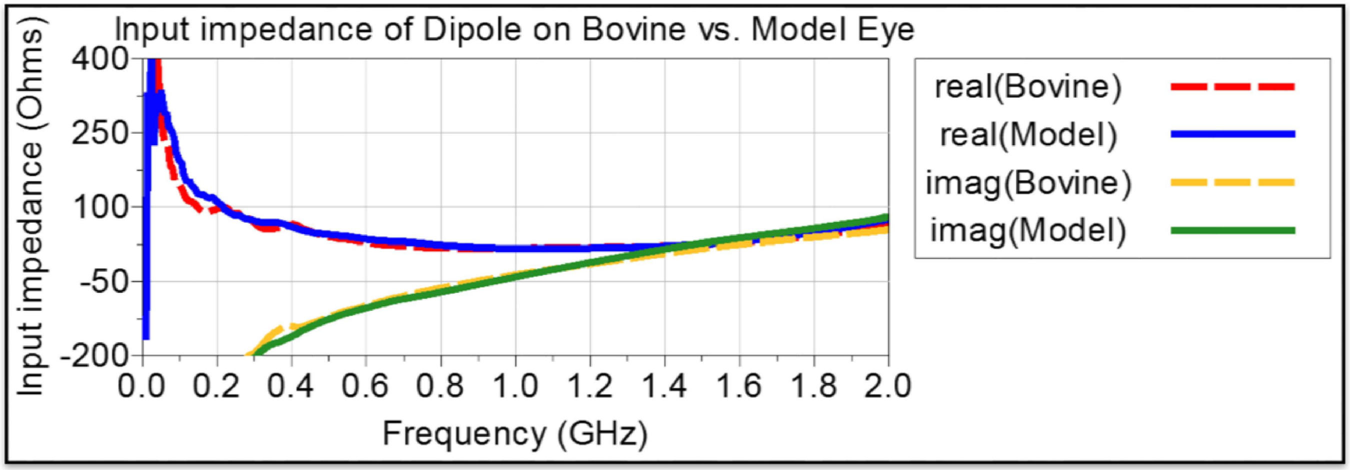


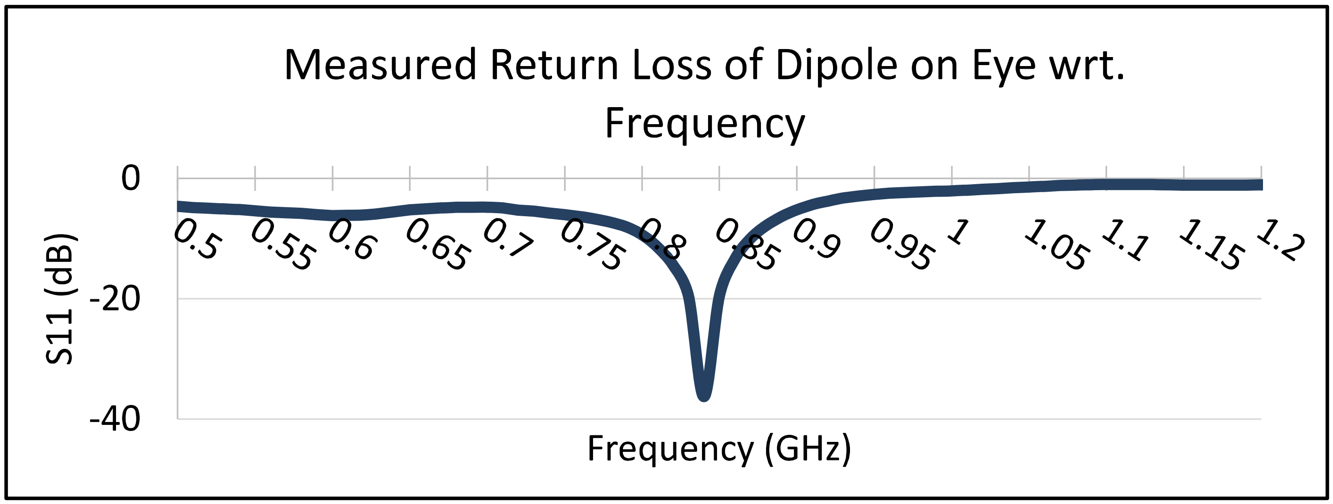
Media	Conductivit y [S/m]	Relative permittivi ty	Loss tangen t	Wave-length [m]
Air	0	1	0	0.361
Cornea	1.36	55.51	0.53	0.046
Aqueous Humor	1.5	65	0.5	0.04
Lens	0.77	46.71	0.36	0.052
Vitreous Humor	1.61	68.92	0.51	0.042


Effect of Vitreous Humor on GSM850 Lens-Dipole
Return Loss (dB)
-4.5
-5.0
-5.5
-6.0
-6.5
-7.0
-7.5
-8.0
-8.5
-9.0
-9.5
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
Frequency (GHz)
dB(Diele_const_60)
dB(Diele_const_65)
dB(Diele_const_69)
dB(Diele_const_75)


Effect of Vitreous Humor on PCS1900 Lens-Dipole
Return Loss (dB)
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
1.0
1.4
1.8
2.2
2.5
Frequency (GHz)
dB(Diele_const_60)
dB(Diele_const_65)
dB(Diele_const_69)
dB(Diele_const_75)

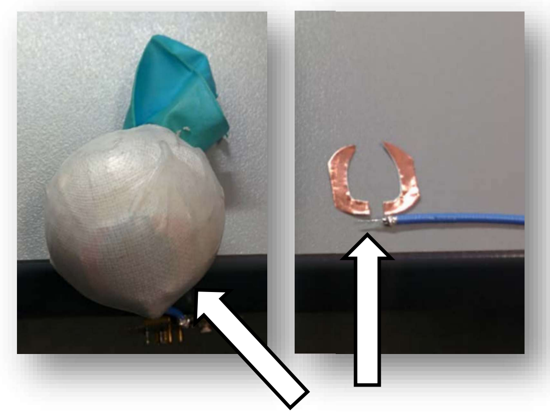
In-house eye model





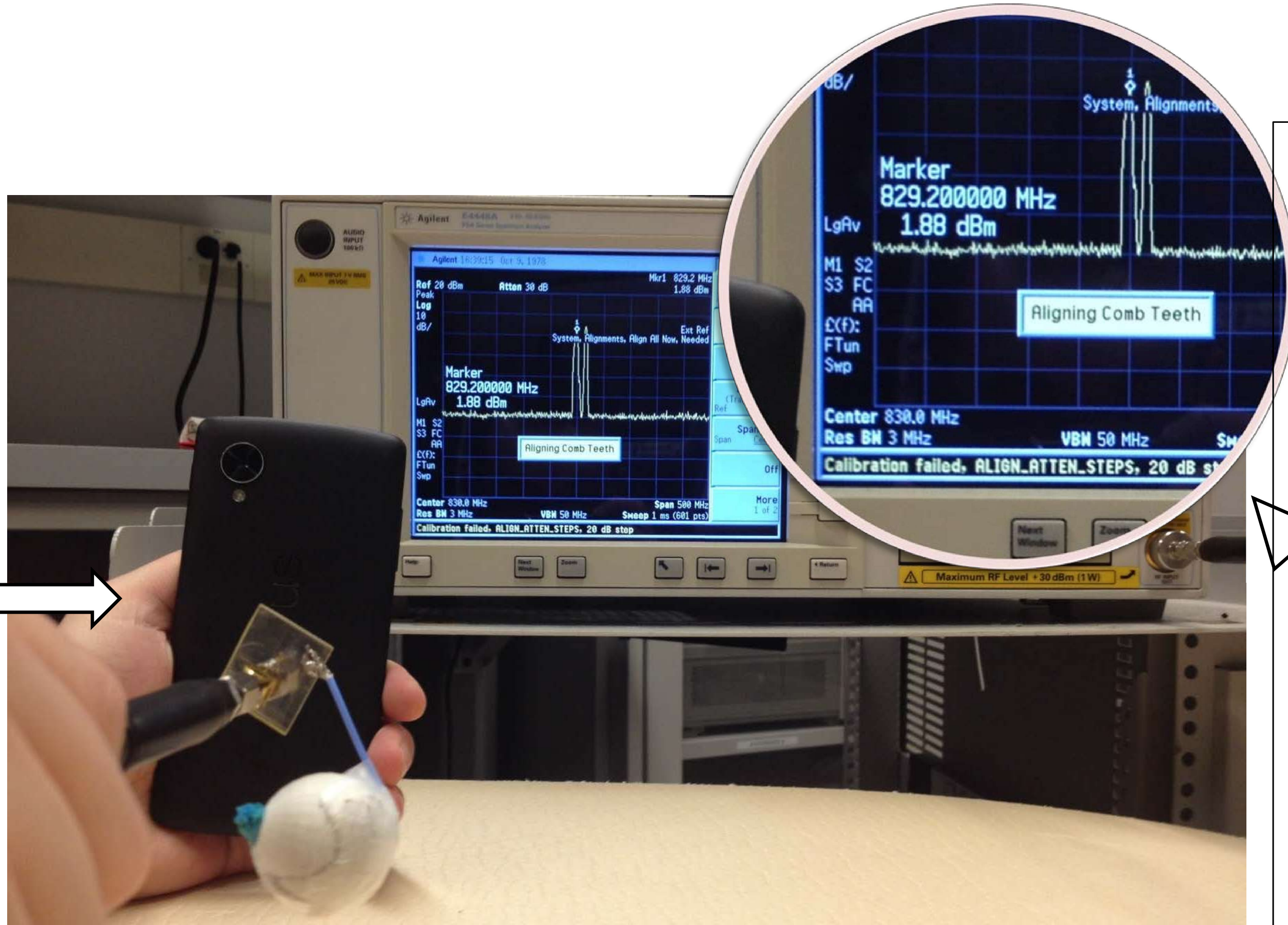
Vs. 10K commercial one

Model eye (polyurethane encased saline solution)



Captured Power by Dipole on Eye

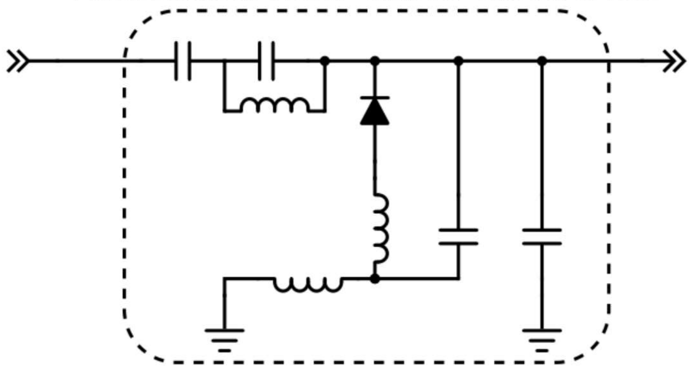
Cellular phone held in antenna Far-Field wrt. dipole antenna on eye



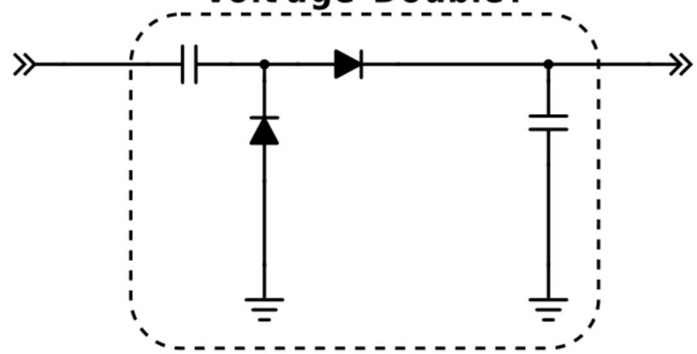
- Power captured during cellular uplink
- Dual band created from GSM channel hopping
- Maximum ~2dBm captured from cellular emission

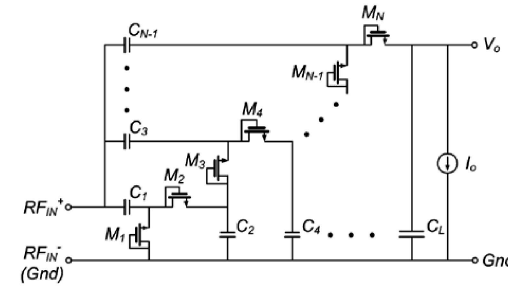
Rectifier Topologies

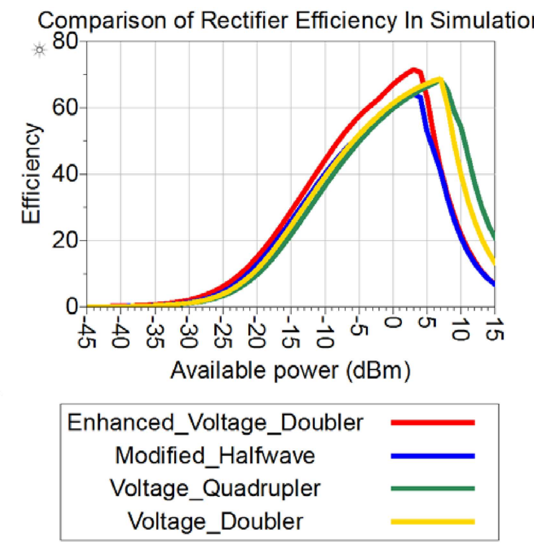
Enhanced Half Wave Rectifier



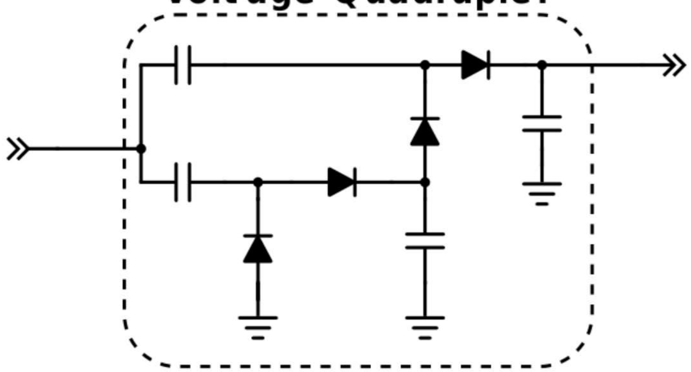
Voltage Doubler



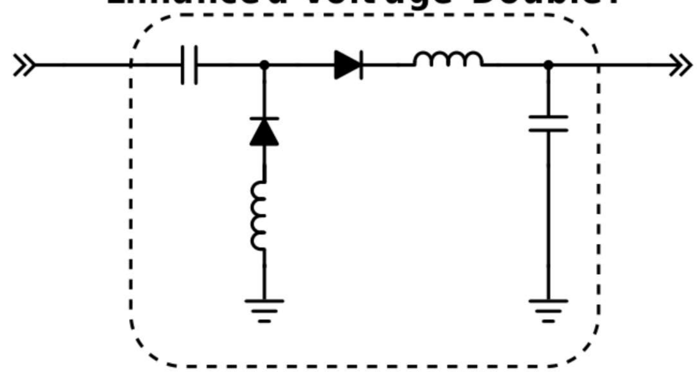




Voltage Quadrupler

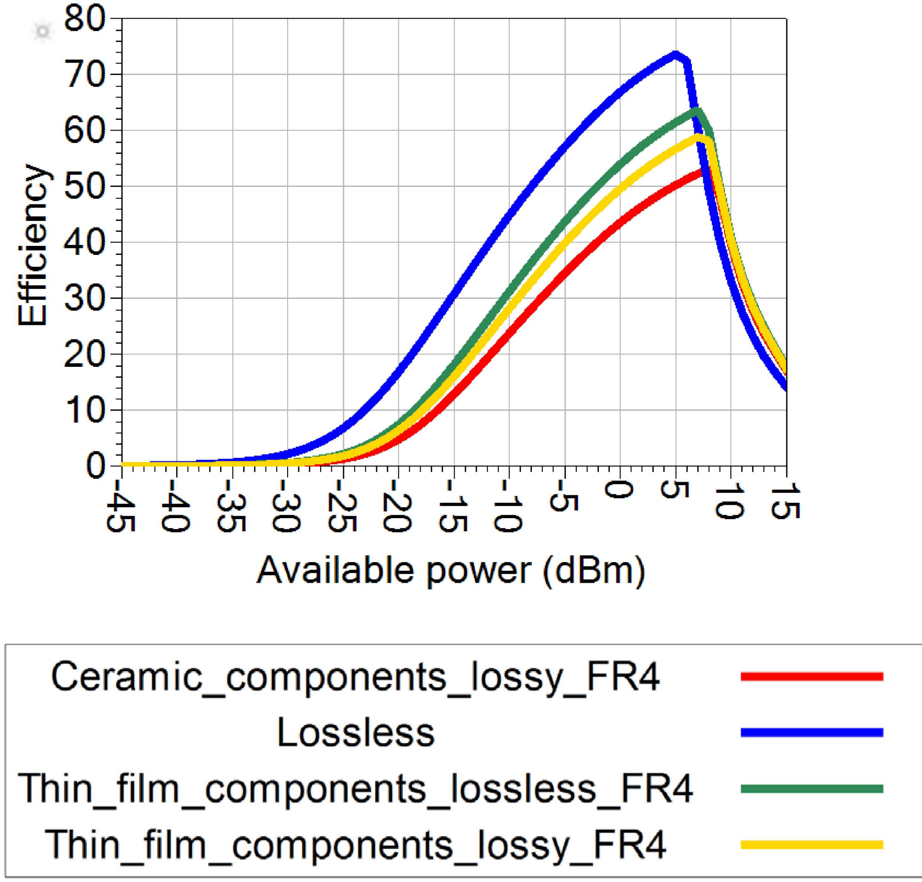


Enhanced Voltage Doubler



Chosen Rectifier

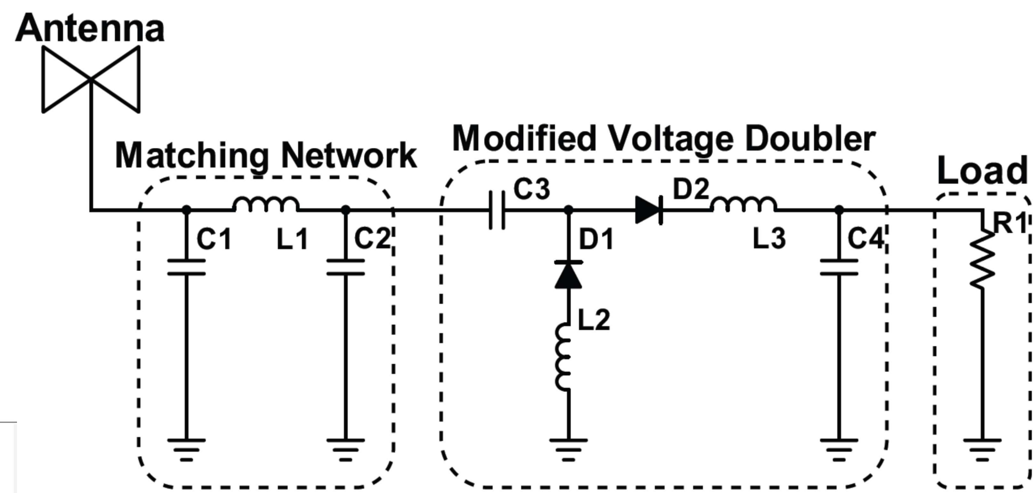
Simulation of Model for Loss in the Chosen Rectifier

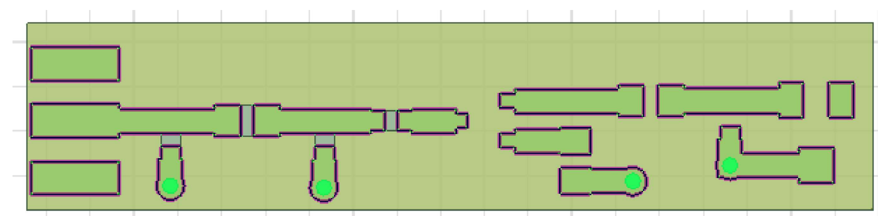


Rectifier uses a modified voltage doubler:

- Inductors added to each branch of the diode
  - ○ Inductor improves RF-DC conversion efficiency

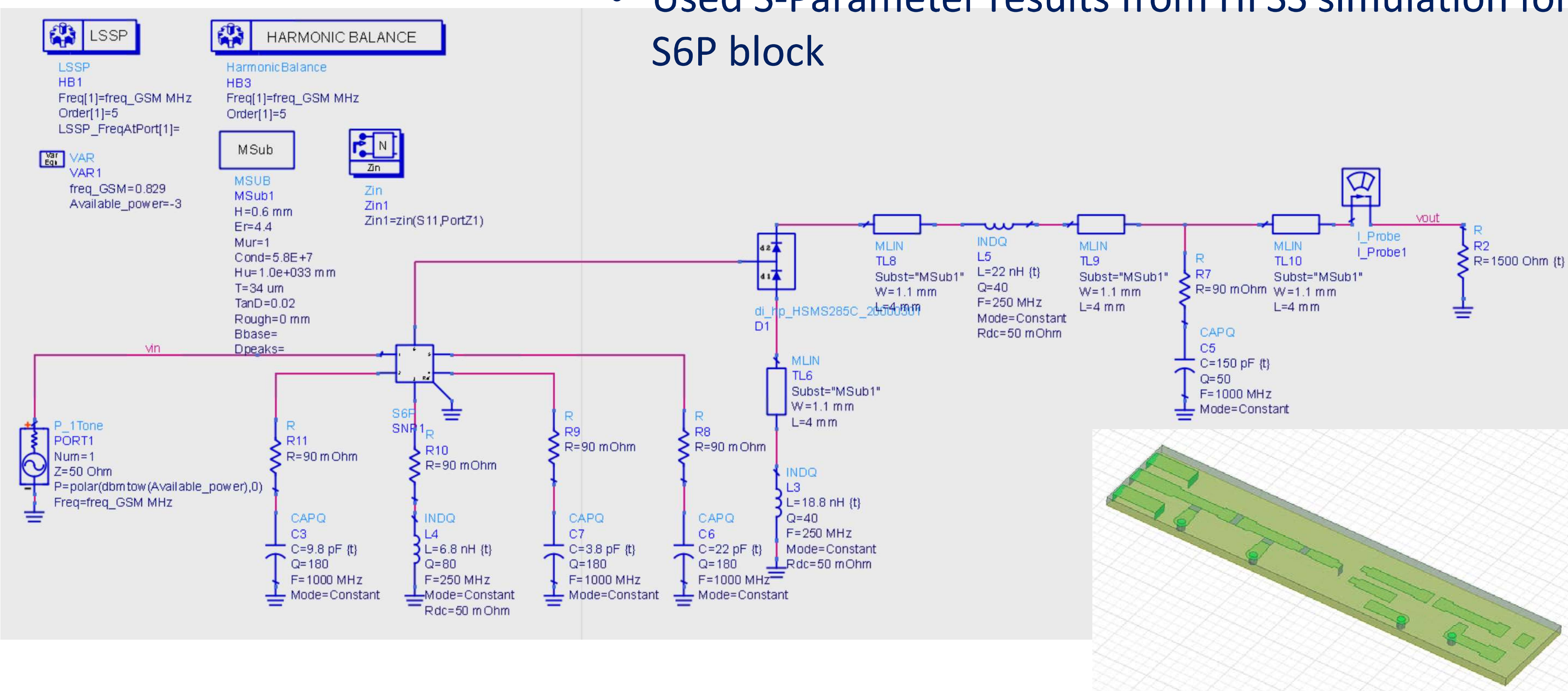
    Thin-film capacitors and wire-wound resistors were used to minimize component loss



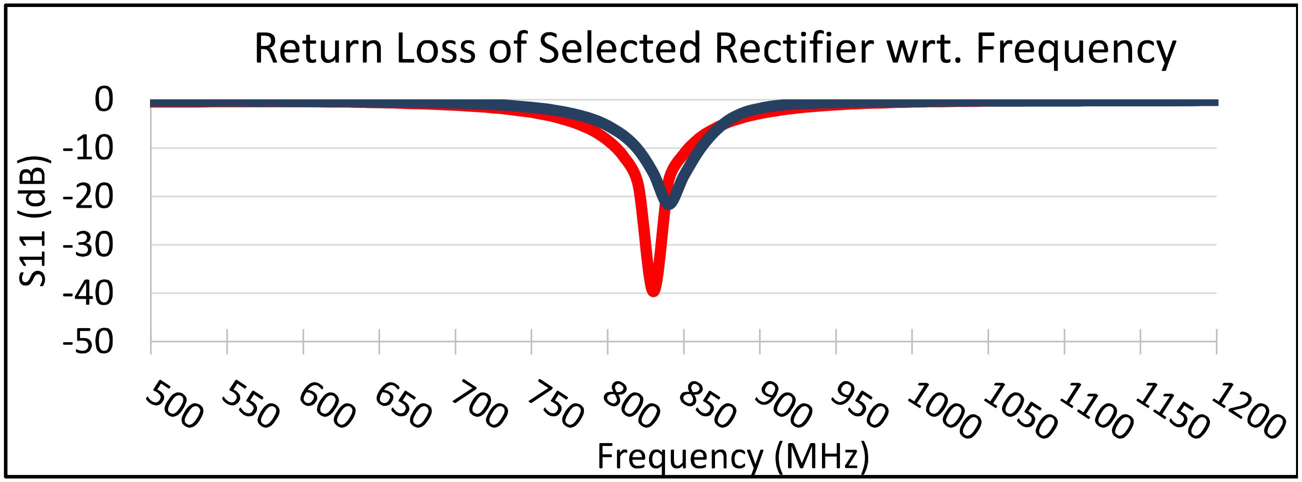


Rectifier Prototype

- Used LSSP and HB for "Frequency" and "Input Power" in separate simulations
- Used component quality factor and loss found from datasheets
- Used S-Parameter results from HFSS simulation for the S6P block

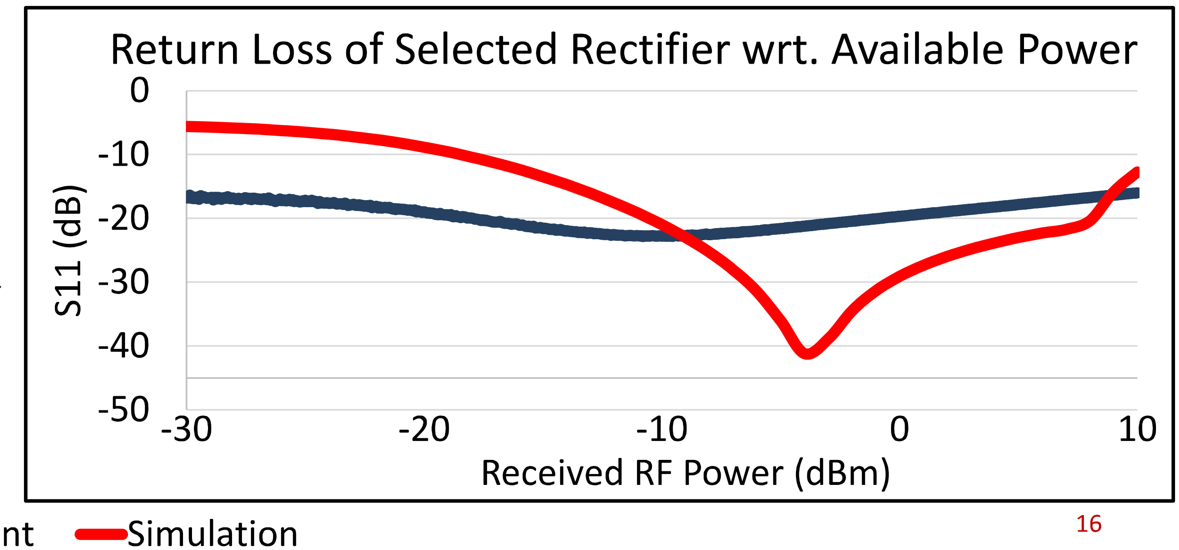


Rectifier Input Performance

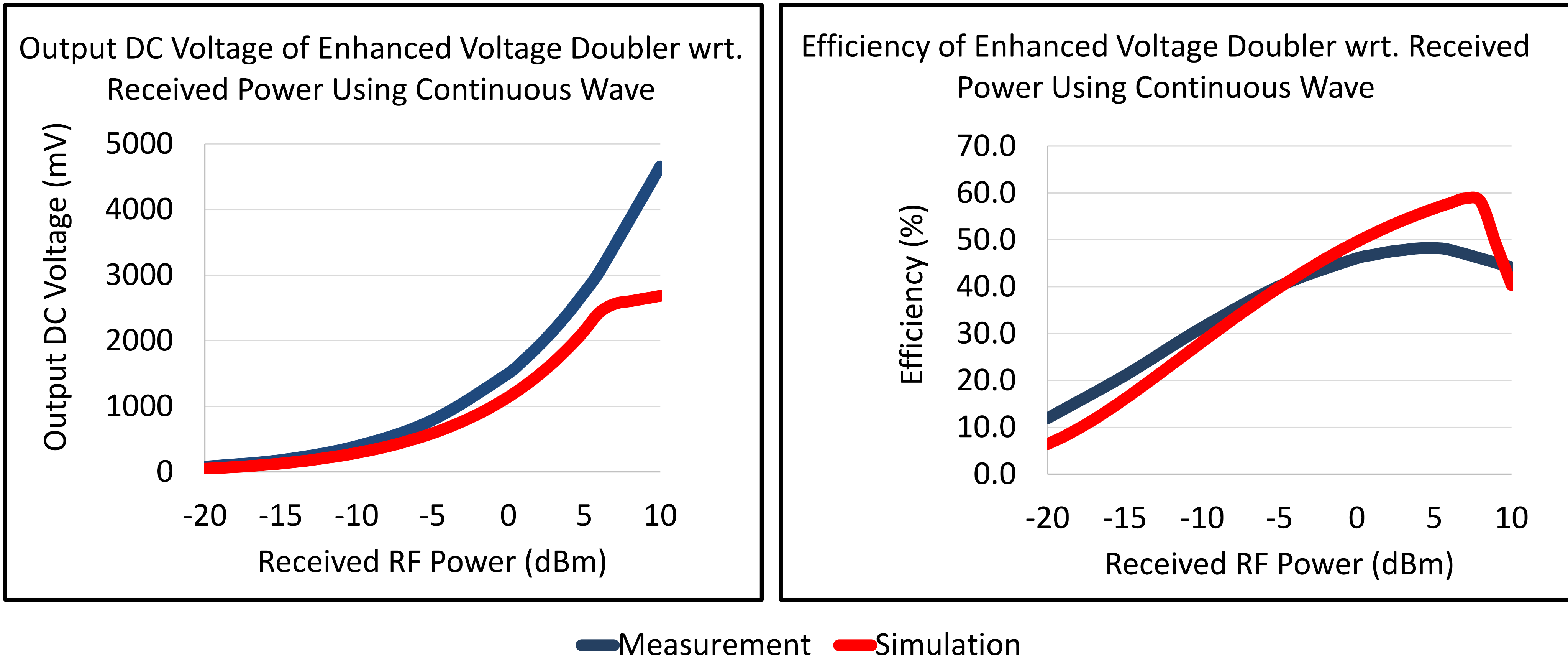


Measured Rectifier BW at -10dB wrt. 0dBm available power: 820—860MHz

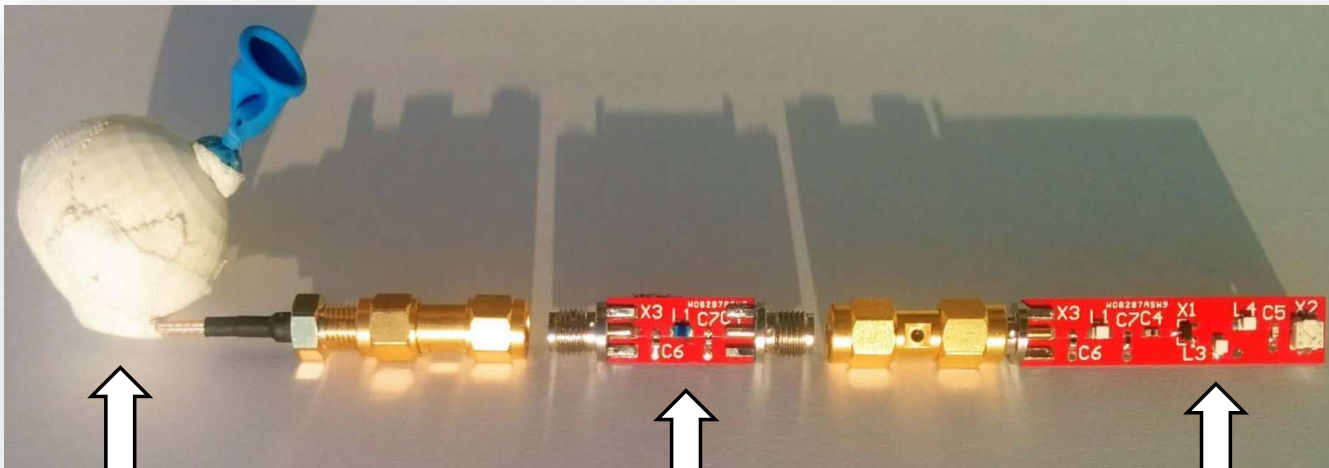
Measured Rectifier BW at -10dB wrt. 837MHz as center frequency: -30dBm - 10dBm



Rectifier Output Performance



Energy Harvesting from Antenna on Eye



- Dipole antenna
- Electrically realistic eye model

Antenna matching network to 50Ω

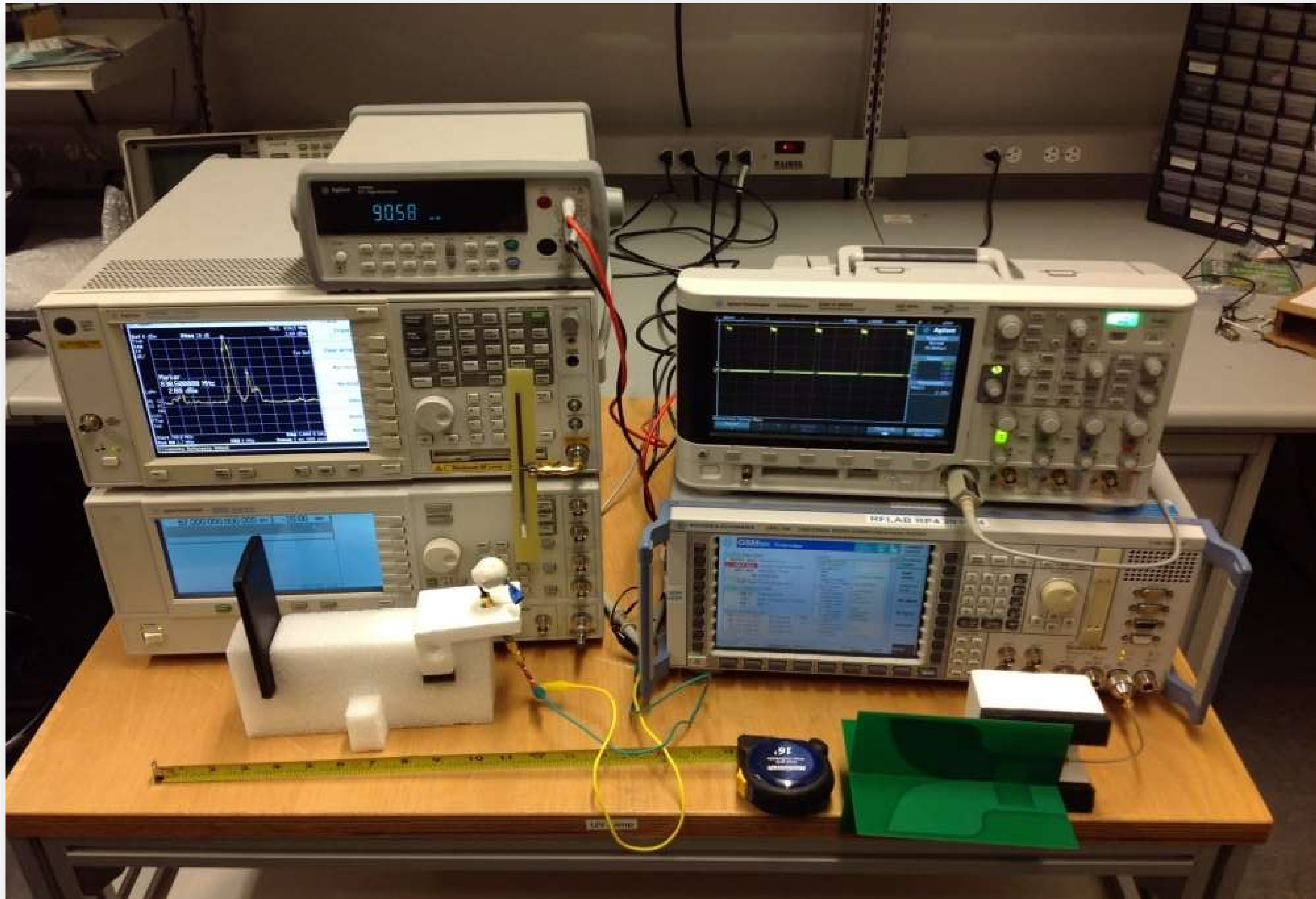
- Rectifier matching network to 50Ω
- Rectifier
- DC load

Rectenna system summary:

- Energy Harvested from cellular spectrum of GSM-850 Uplink: 824.2 to 849.2MHz
- Rectifier and matching made from FR4 PCB and off-the-shelf electrical components
- Load optimized for maximum rectifier efficiency (R_{Load}=4916Ω)

Energy Harvesting: Measurement Set-up

- CMU emulated a base-station
- CMU used for GSM-850 downlink
- Phone uplink @ TRP =31dBm
- No modification to phone hardware and firmware
- Harvester placed 7 inches from source (phone)
- Oscilloscope used to measure voltage at DC load

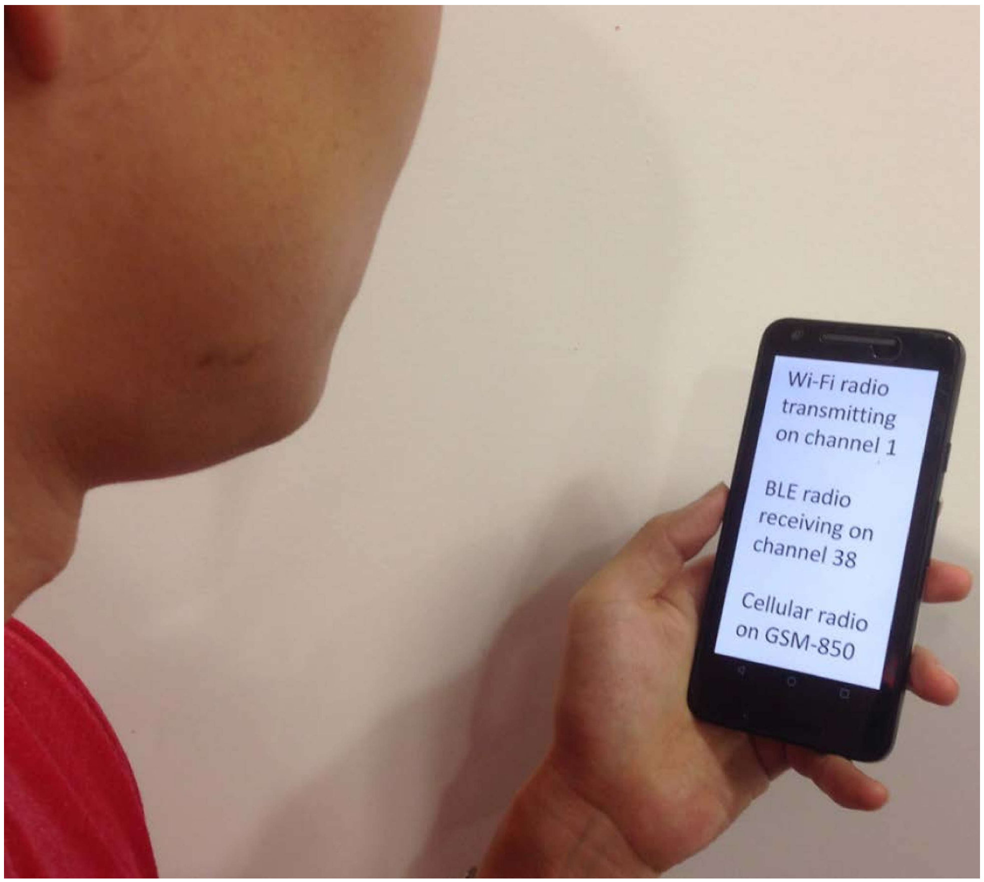


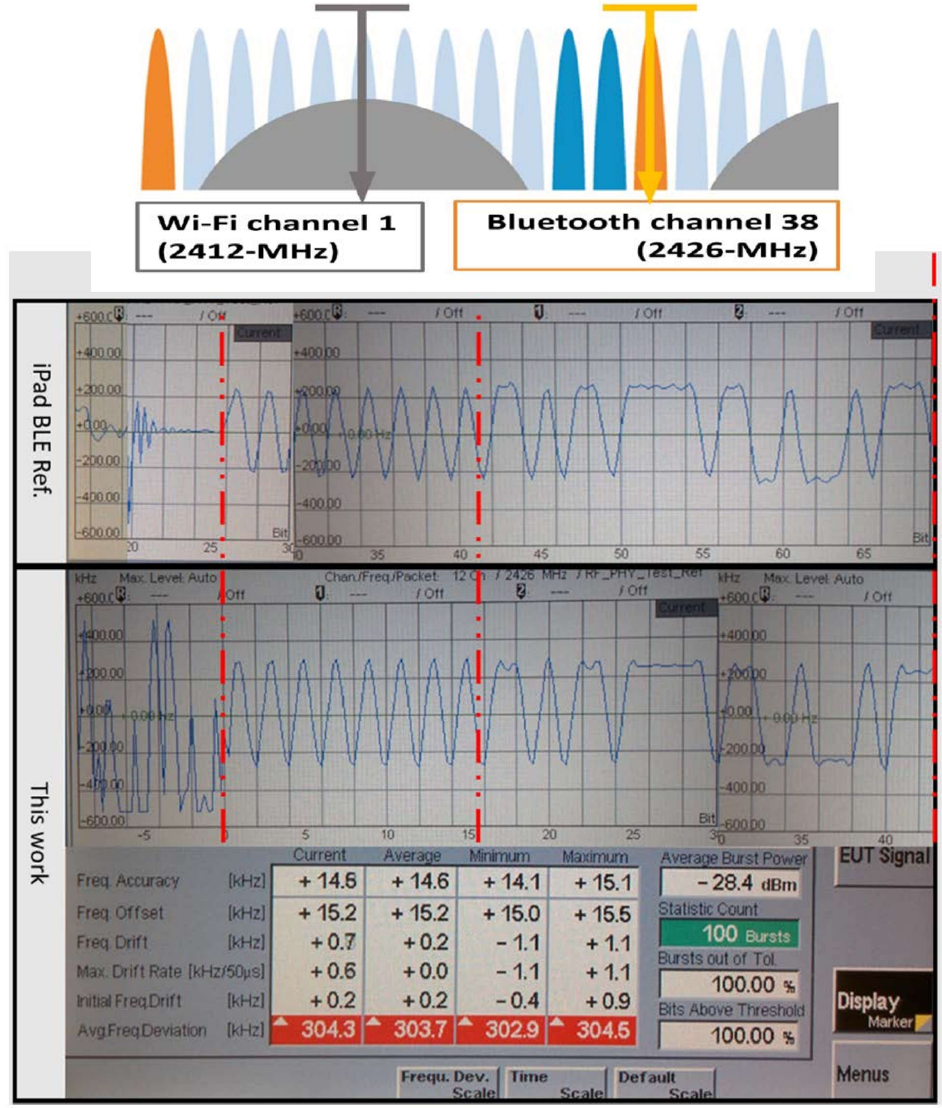
Energy Harvesting: Measurement Set-up

Measurement at DC load:

- Pulsating output voltage for periodic GSM uplink carrier
- Duty cycle of carrier bursts: 12.5% (0.577ms)
- Load optimized for maximum rectifier efficiency (R_{Load}=4916Ω)
- Rectified voltage from carrier burst: 2.1V (10mV ripple)
- Rectified DC power of a carrier burst: -0.5dBm

Enabling Communication





Acknowledgments

Major Funding:
- National Sciences and Engineering Research Council of Canada
- Ontario Centres of Excellence
- Medella Health

Other Students:
- Luxsumi Jeevananthan
- Shadi Dashmiz
- MohammadSadegh Faraji-Dana
- Sung Eun Kim
- Zhichao Li

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Reference Publications:
- G. Shaker et al., Electronics Letters, 2016
- L. Chen et. al., IEEE AP Magazine, 2017
- L. Chen et. al., APS 2017